Examining Relationships Between the Vertical Structure of Deep Convection and Upper Tropospheric Humidity Using AIRS

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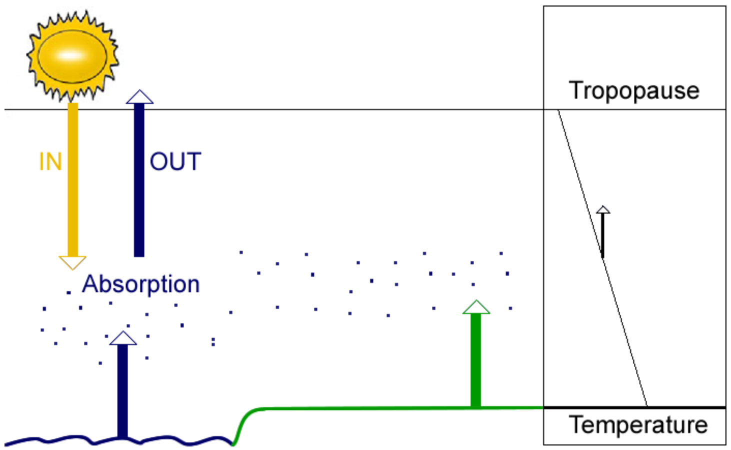
Overview

- Introduction
- Data & Method
- Preliminary Results
- Future Work

Introduction: The Water Vapor Feedback

- Water vapor: the dominant greenhouse gas
  - ▷ Continuum absorption in IR
  - ▷ Abundance in atmosphere
- Atmospheric capacity for water vapor increases with increasing temperature $\Longrightarrow$ expect feedback to temperature changes



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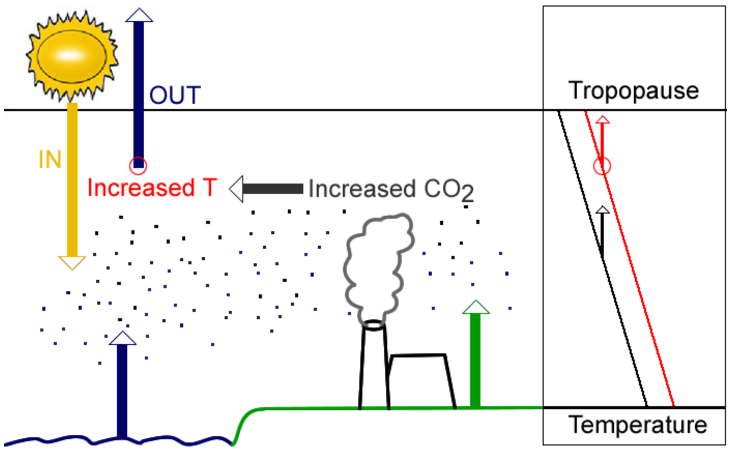

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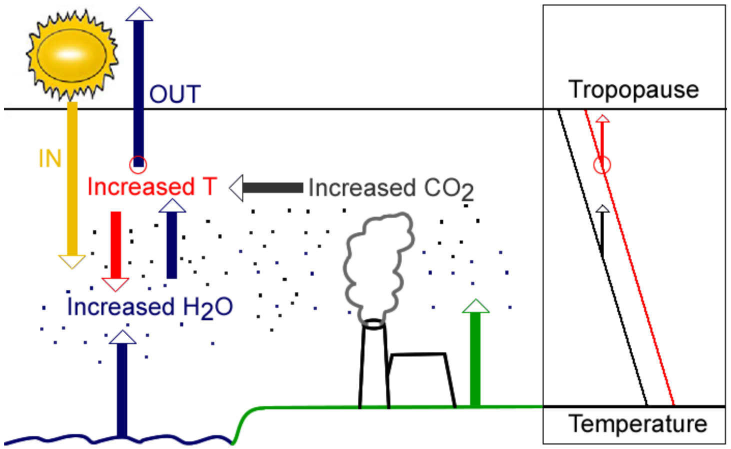

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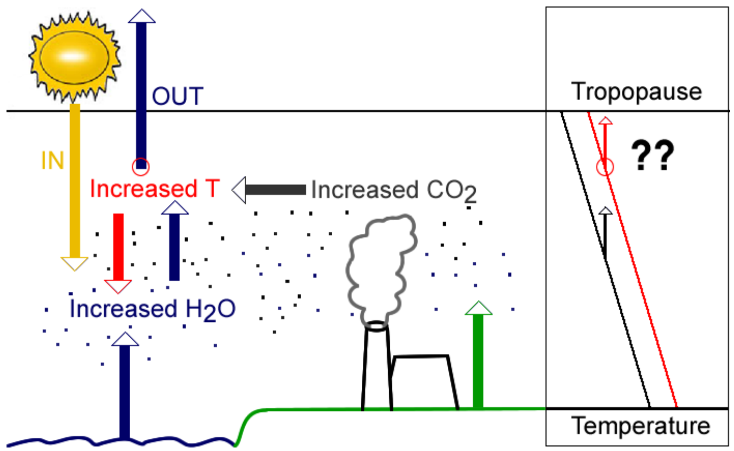
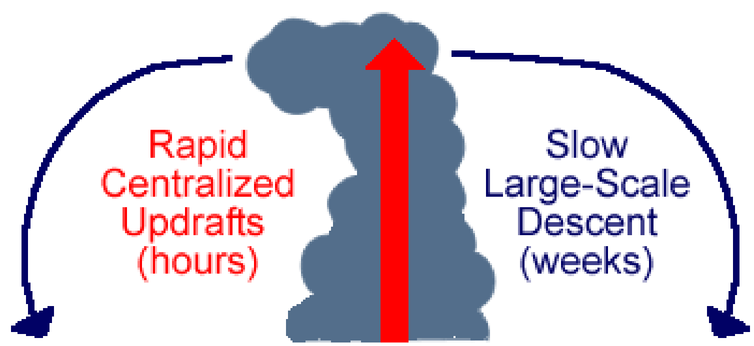


- Strength of feedback remains uncertain: estimates range from zero feedback to constant RH ($\sim$ 170%), or more!

Introduction: Upper Tropospheric Water Vapor

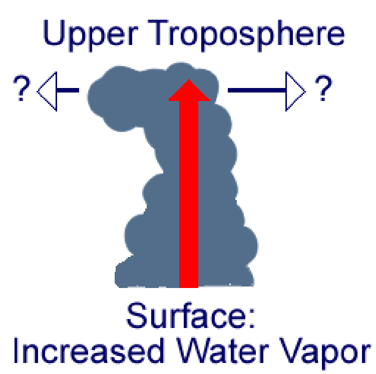
- Climate models: 35% of total radiative water vapor feedback from tropical UTH (100-500 mb)
- Cold temperatures in tropical, subtropical UT mean that a small change can have a large effect
- Conceptual model of tropical upper tropospheric water vapor:
    - Source: rapid, highly localized convection
    - Sink: slow, large scale descent



- Water vapor distribution largely controlled by distribution of convection

Introduction: The Role of Convection

- Convection can both hydrate and dehydrate the UT
  - ▷ Retention and evaporation of droplets ⇒ moistening
  - ▷ Vapor condenses onto droplets and precipitates ⇒ dehydration
  - ▷ Detrainment into already saturated air, drops fall out ⇒ no change
- Current climate models: moisture detrainment controlled by temperature (altitude) of detraining layer
- Other influences: cloud/precip microphysics, mesoscale downdrafts
- Strength of modeled water vapor feedback highly dependent on detrainment scheme



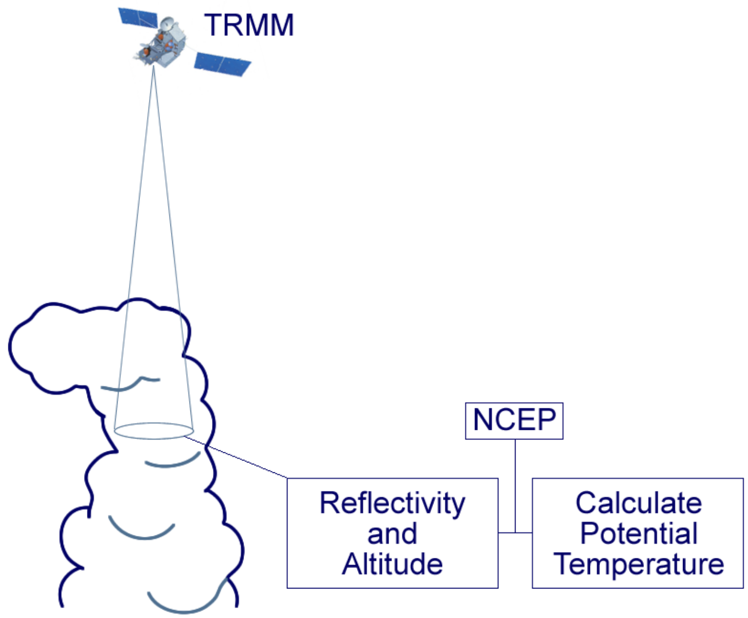
Introduction: This Study

- Previous studies of convective detrainment in the UT:
  - ▷ *in situ*: highly localized observations of short term evolution
  - ▷ Models: larger scale, longer term but necessarily simplified physics
  - ▷ Satellites: vertical structure unknown, water vapor observations sparse
- Recent satellite technology provides unprecedented opportunities
  - ▷ TRMM Precipitation Radar: vertical characterization of convective systems
  - ▷ AIRS: high vertical resolution global coverage of water vapor into the upper troposphere
  - ▷ MODIS: Ice particle sizes at cloud top
- Link these observations by a transport scheme
- Preliminary proof of concept study:
  - ▷ Detrainment altitude
  - ▷ Cloud/precip microphysics
  - ▷ Role of ice in UT water vapor feedback

Method: Data

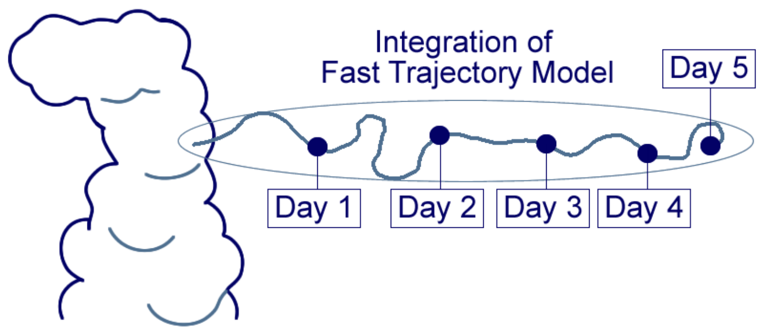
- TRMM Precipitation Radar
  - ▷ 2A25 Volumetric Radar Reflectivities
    - Echo from water and ice droplets within a volume
    - Higher reflectivities = larger droplets or higher concentrations
    - Measure of convective intensity
  - ▷ Reliable for convective systems larger than footprint (4.3 to 5 km)
- AIRS
  - ▷ Combination of IR and microwave instruments
  - ▷ Rapid global coverage ($\sim 2\times$ per day)
  - ▷ Horizontal resolution $\sim$ 40 km at nadir; vertical resolution $\sim$ 2 km.
  - ▷ Slight dry bias in upper troposphere relative to ECMWF
- MODIS
  - ▷ Cloud ice particle effective radius derived from visible and infrared radiances
  - ▷ Along track or daily $1^\circ \times 1^\circ$ gridded product

Method: Finding Convection



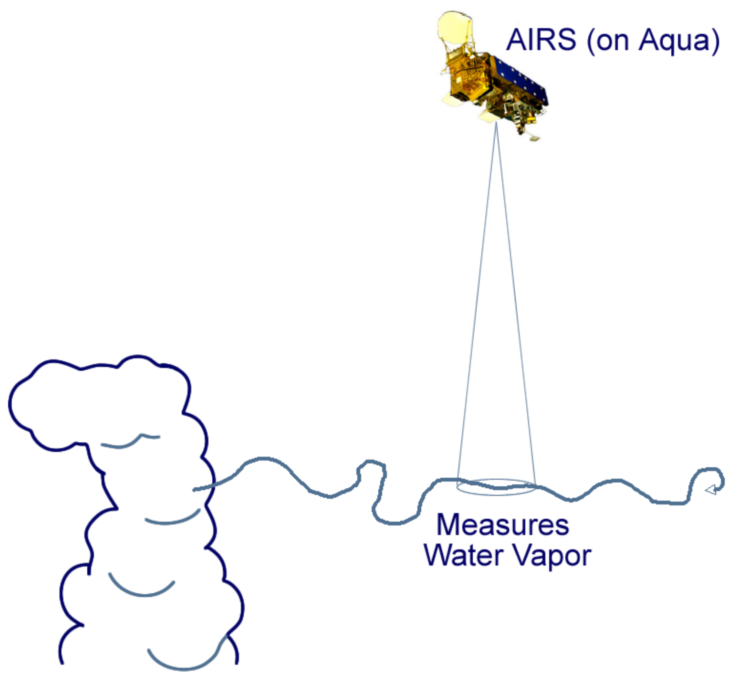
- Scan TRMM observations for:
  - ▷ Deep convection (altitude $\geq$ 10 km)
  - ▷ TRMM PR Z $\geq$ 20 dBZ (noise threshold $\sim$ 17 dBZ)
- Calculate potential temperature from NCEP geopotential heights, assume TRMM altitude $\equiv$ NCEP geopotential height, and interpolate
- Store MODIS mean cloud ice effective radius for associated gridbox

Method: Integrating Trajectory



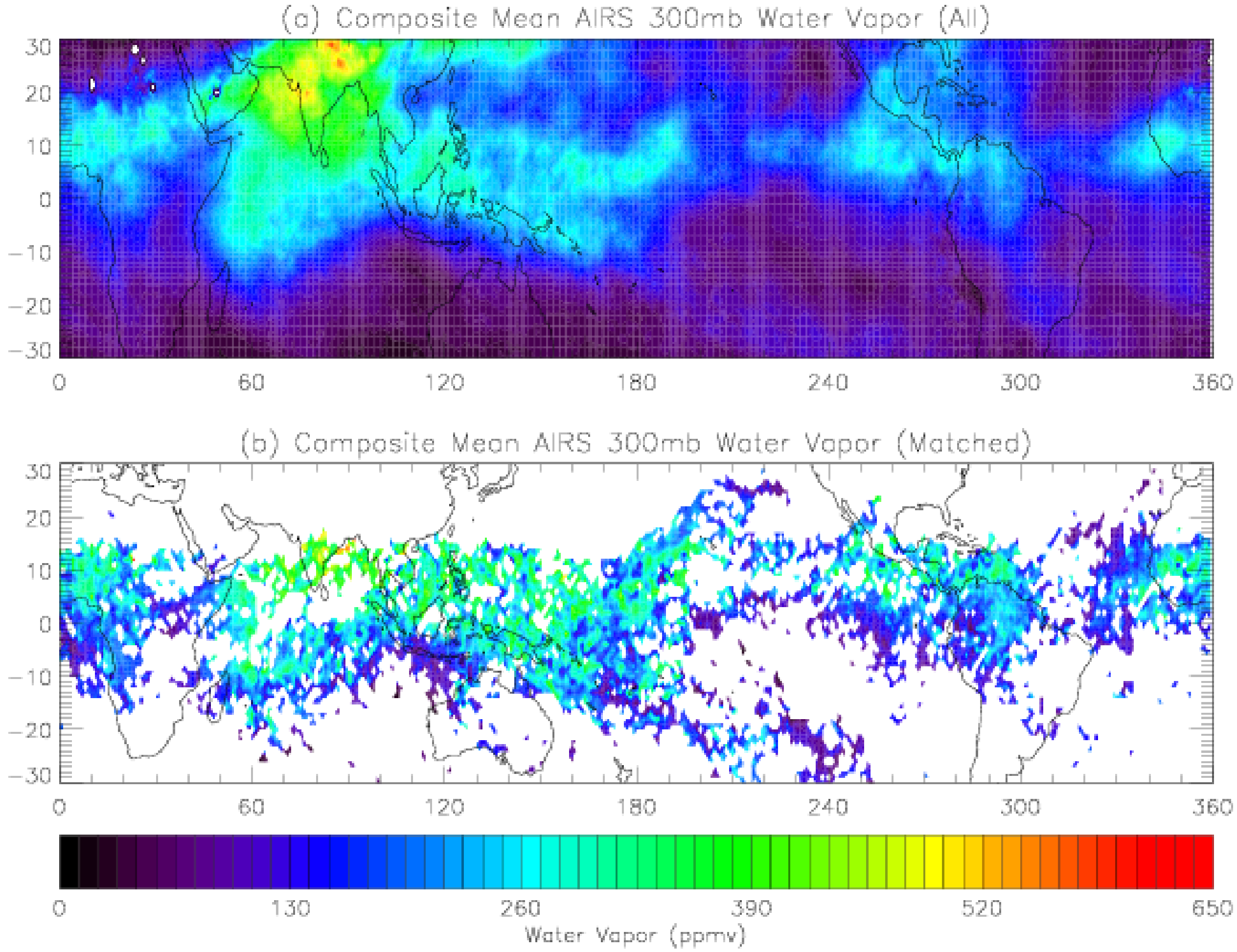
- Fast Trajectory Model - ftraj (M. Schoeberl)
  - ▷ Five day forward trajectory with timestep = 0.02 days ($\sim$ 30 minutes)
  - ▷ UKMO winds (Updated daily at 12 UTC, 2.5° lat × 3.75° lon)
  - ▷ Diabatic heating rates derived from UKMO using a radiative transfer scheme
- Position stored at each timestep

Method: Matching Water Vapor



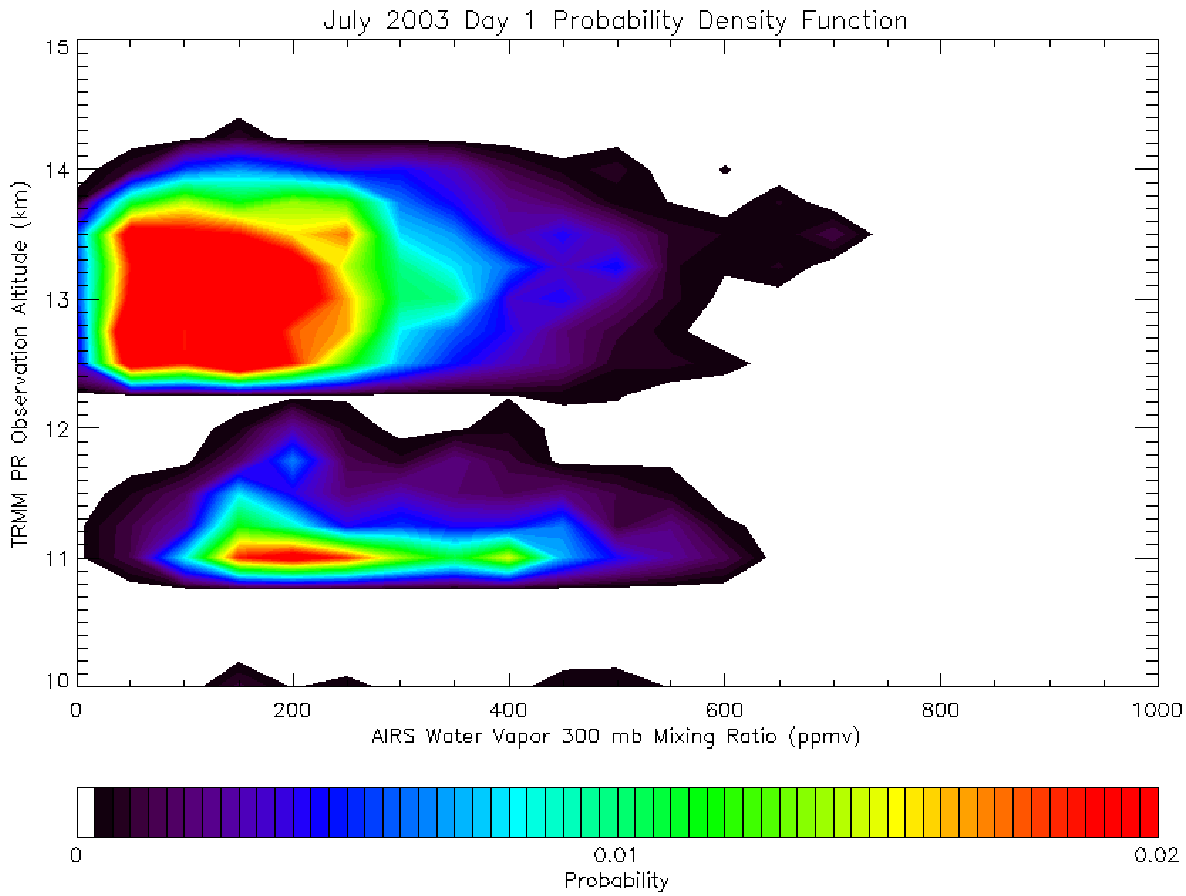
- Search for AIRS observations close in space and time to trajectory point
  - $1^\circ \times 1^\circ$ box & 30 minutes following trajectory passage
  - Include unvalidated overland measurements
- If multiple locations, use mean humidity
- Linearly interpolate from AIRS standard pressure levels

Results: 300 mb Vapor



- Many of the maxima are influenced by convective events observed in TRMM
- Consistent with conceptual model - bolsters confidence in the method

Results: 300 mb Vapor Evolution by Original Altitude



- ▷ Apparent bimodal outflow distribution: 11-12 km, 12.5-14 km
- ▷ Outflow altitude looks too high! Likely due to estimation of θ

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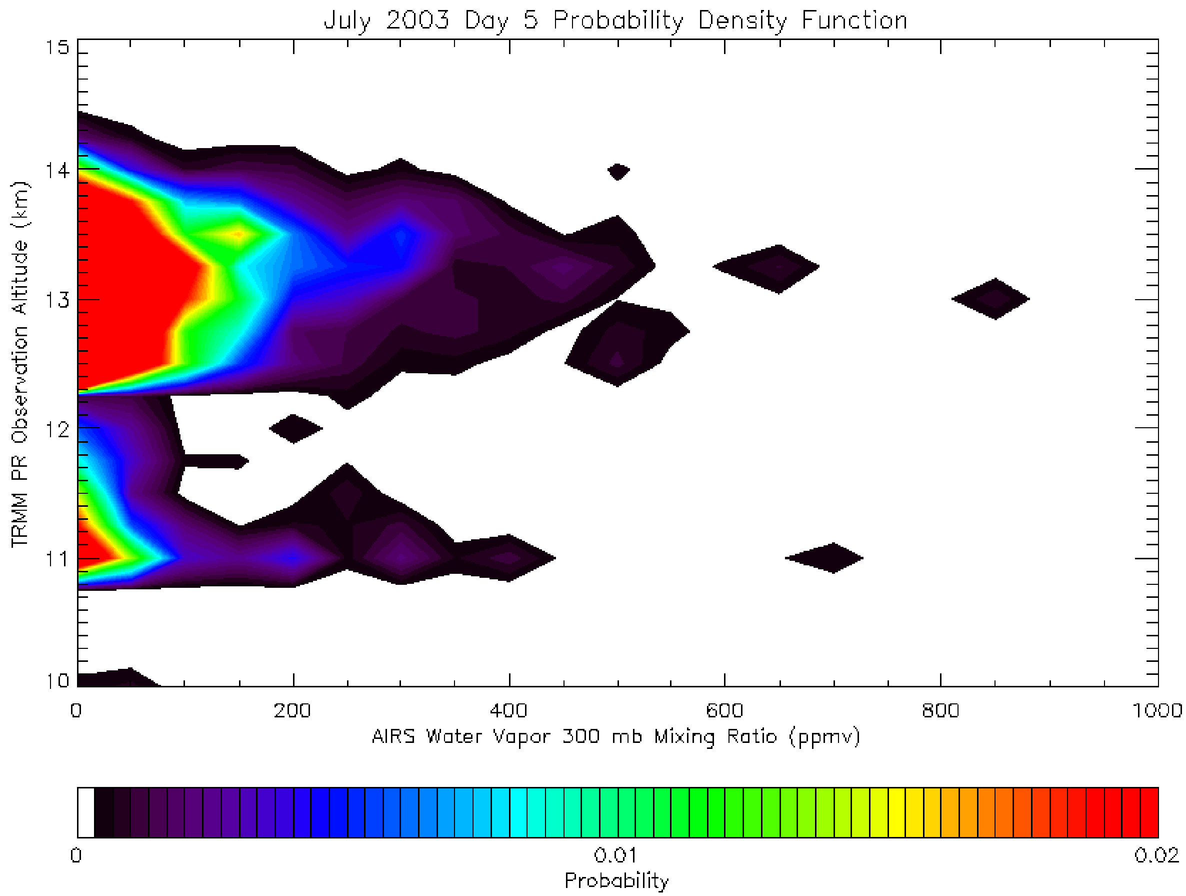
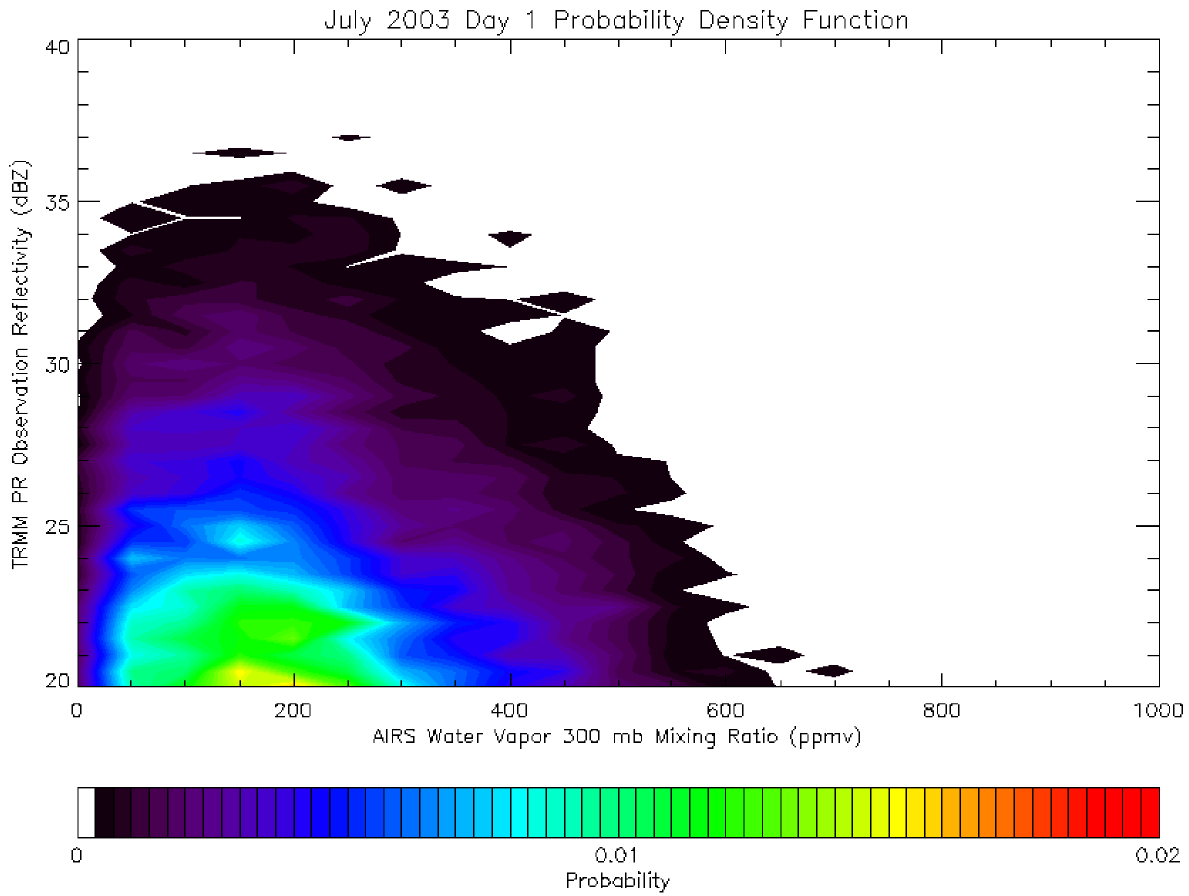


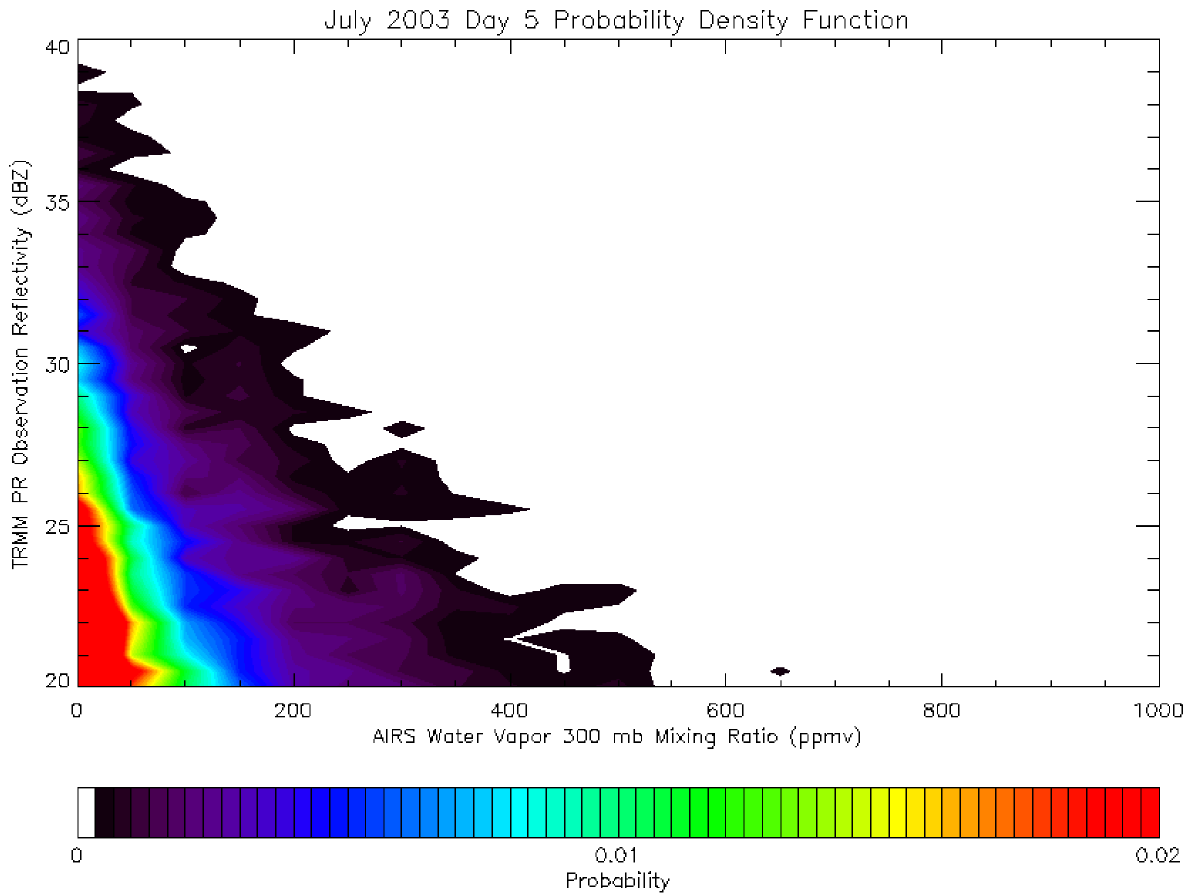
- Apparent bimodal outflow distribution: 11-12 km, 12.5-14 km
- Outflow altitude looks too high! Likely due to estimation of θ
- Higher altitudes may dehydrate more slowly; gap blurs

Results: 300 mb Vapor Evolution by Original Reflectivity



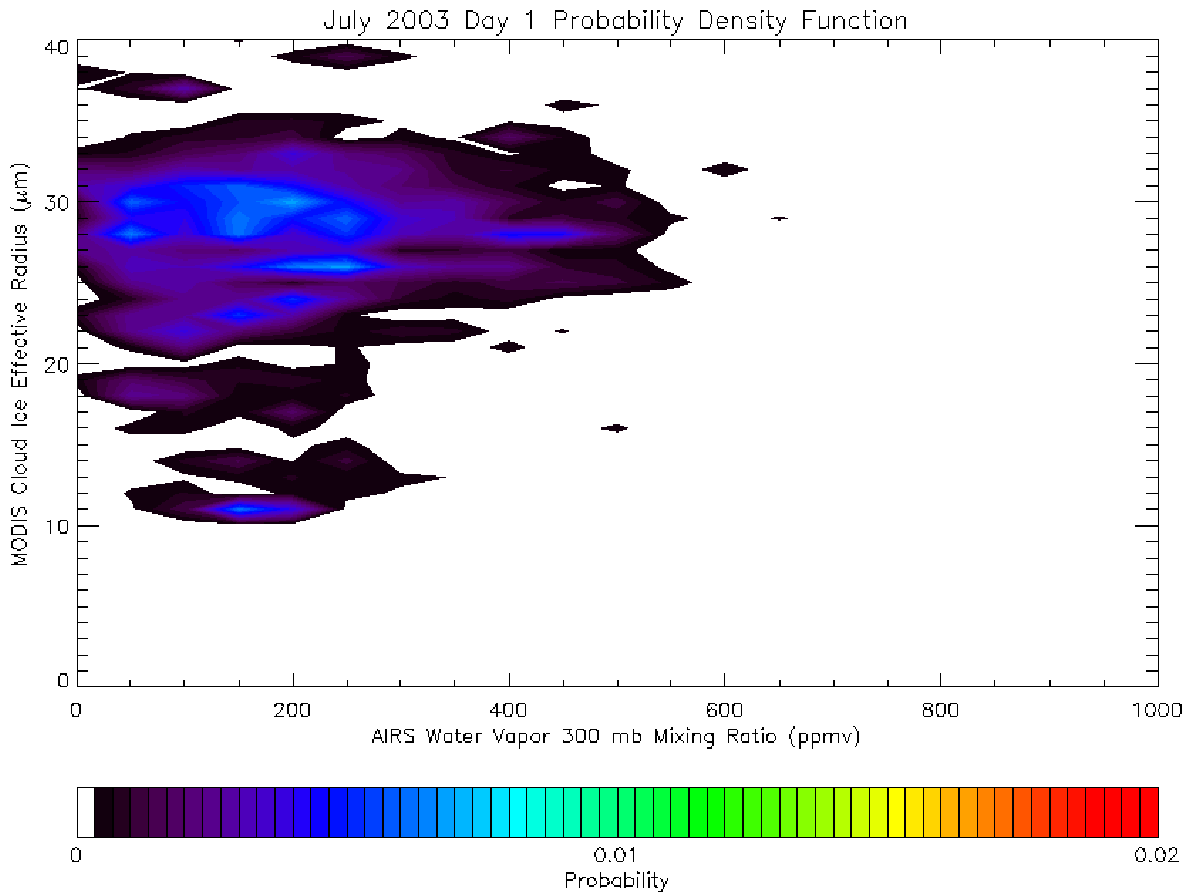
- ▷ Stronger convection seems to detrain drier air

Results: 300 mb Vapor Evolution by Original Reflectivity



- ▷ Stronger convection seems to detrain drier air
- ▷ Detrainment from higher reflectivities appears to dehydrate more quickly
- ▷ Stronger convection ⇒ higher precip efficiency ⇒ drier air downstream

Results: 300 mb Vapor Evolution by Original Crystal Size



- Main cluster between 20 and 35 μm
- Smaller effective radius/lower humidity due to higher detrainment altitude?

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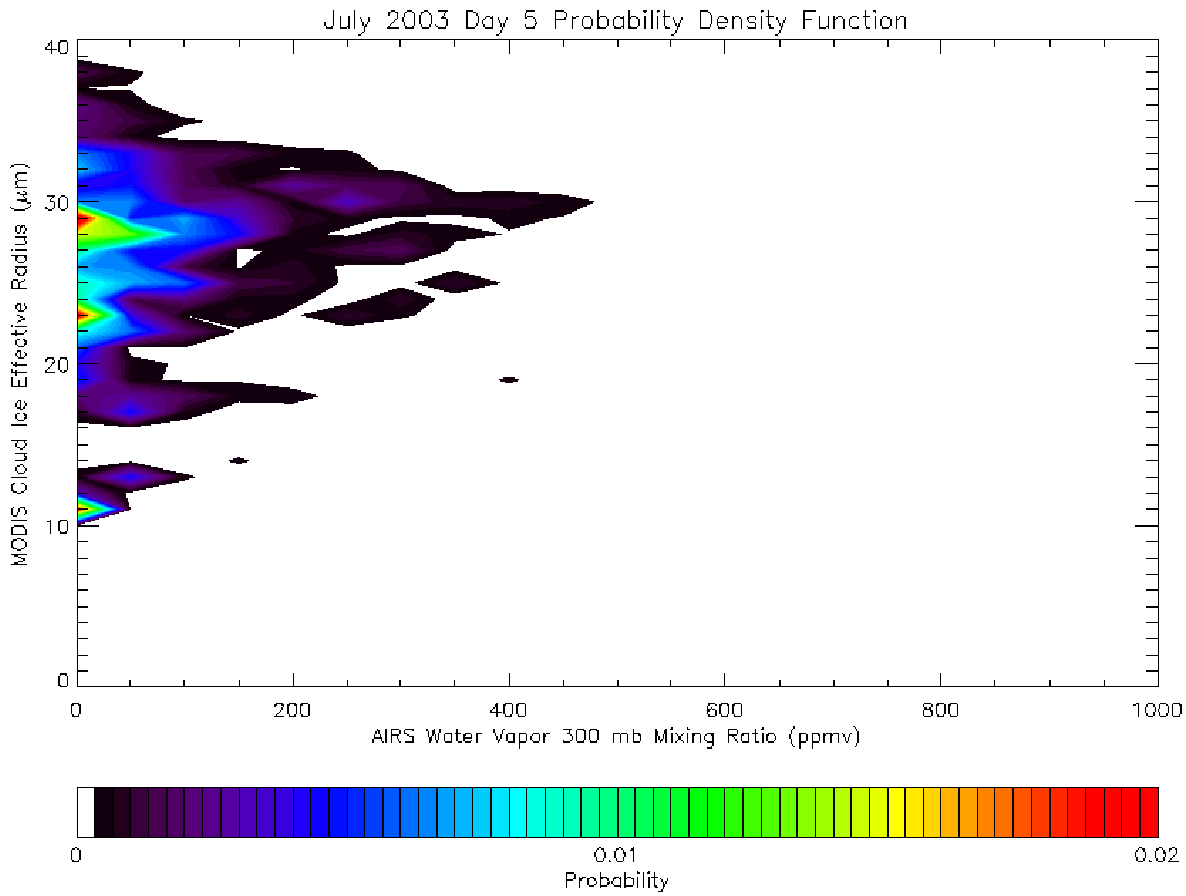

- Main cluster between 20 and 35 μm
- Smaller effective radius/lower humidity due to higher detrainment altitude?
- Evaluate gridded vs. along-track

Summary of Results

- Preliminary results indicate:
  - ▷ Detrainment at higher altitudes may dehydrate more slowly
  - ▷ Bimodal distribution of detrainment - continental vs. maritime convection?
  - ▷ Larger reflectivities may dehydrate more quickly
- Estimation of potential temperature a major weakness
- Need to evaluate MODIS results, particularly level 3 vs. level 2
- Otherwise, the method and data used in this preliminary study show significant potential for use in broader and longer term studies
  - ▷ Develop method to check for cirrus along track (ISCCP DX)
  - ▷ Investigate regional/seasonal variability over 2 years
  - ▷ Case studies: bin trajectories by system; match with aircraft studies
  - ▷ "Train" mixing parameterization along trajectory by tracking individual trajectories
  - ▷ Evaluate role of boundary layer aerosols (e.g., biomass burning)